SIMULATION OF THE SPECTRAL BANDS OF THE CCD AND WFI CAMERAS OF THE CBERS SATELLITE USING AVIRIS DATA

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1.INTRODUCTION

In mid-99 Brazil and China will be launching into orbit the first satellite of the program named *China-Brazil Earth Resources Satellite* (CBERS). The goal of this work is to simulate the spectral resolution of the images generated by the CCD camera and the Wide Field Imager (WFI) on board CBERS, using data of the *Airborne Visible/Infrared Imaging Spectrometer* (AVIRIS) of the *Jet Propulsion Laboratory* (JPL). The AVIRIS measured images of several areas of the North and Mid-West regions of Brazil in August and September of 1995 during the experiment *Smoke/Sulfate, Clouds and Radiation-Brazil* (SCAR-B).

This study was motivated by the possibility of using the AVIRIS images to simulate the spectral response functions that define the spectral bands of both cameras on CBERS. This method was developed at JPL by Green and Shimada (1997), and was used on the on-orbit calibration of the Optical Sensor (OPS) of the *Japanese Earth-Resources Satellite* (JERS-1). For the JERS-1 experiments AVIRIS underflew the OPS sensor in 1992, 1993, and 1994. The AVIRIS data were transformed to the OPS spectral bands by a spectral convolution and were spatially registered to the OPS image. The AVIRIS simulated OPS images were used to establish radiometric calibration coefficients for OPS on-orbit (Green and Shimada, 1997).

2. SENSOR SYSTEM OF CBERS

The CBERS satellite was designed to have a global coverage. It has three cameras for optical observation as well as an environmental collecting system. One characteristic of CBERS is its multi-sensor payload with different spatial resolutions and data collecting frequencies. The first chart gives a summary of the satellite sensors parameter. A brief description of the sensor systems is given below:

The **Wide Field Imager (WFI)** will cover a ground swath of 890-km which provides a synoptic view with spatial resolution of 260m. The Earth surface is completely covered in about 5 days, in two spectral bands centered in 0,___ m(band 10) and 0,83_m (band 11) that corresponds to the red (R) and near-infrared (NIR), respectively.

The **CCD Camera**, provides images of a 113km wide strip, with 20m spatial resolution. Since this camera has a sideways pointing capability of about 32 degrees, it is capable of taking stereoscopic images of a certain area. Any phenomenon detected by the WFI could be located by the CCD camera through the appropriate pointing of its field of view in at most three days. The CCD camera will operate in 5 spectral bands, including a panchromatic band (PAN) with 0,51 to 0.73_m (band 5). The spectral position of the bands 3 and 4 of the CCD camera is similar to the bands 10 and 11 of the WFI camera, to give the possibility of combination of data acquired by both cameras. The bands 1 and 2 cover the spectral intervals of 0,45 to 0,52_m and of 0,52 to 0,59_m, respectively and its temporal resolution is 26 days .

CHART 1 – Summary of the characteristics of the sensors aboard the CBERS

CHARACTERISTICS OF THE SENSORS ABOARD THE CBERS			
CAMERAS =>	**CCD**	**IR-MSS**	**WFI**
SPACIAL RESOLUTION	20 m	80 m (PAN) 80 m (SWIR) 160 m (TIR)	260 m
FIELD OF VIEW	8,3°	8,8°	60°
SWATH WIDTH	113 km	120 km	890 km
TEMPORAL RESOLUTION	26 days nadir 3 days off-nadir – using ±32°sideways pointing capability	26 days	5 days
SPECTRAL BANDS (μm)	1) 0,45 - 0,52 (B) 2) 0,52 - 0,59 (G) 3) 0,63 - 0,69 (R) 4) 0,77 - 0,89 (NIR) 5)0,51 - 0,73 (PAN)	6) 0,50-1,10 (PAN) 7) 1,55-1,75 (SWIR) 8) 2,08-2,35 (SWIR) 9) 10,40 – 12,5 (TIR)	10) 0,63-0,69 (R) 11) 0,77 - 0,89 (NIR)

FONT: INPE (1995), p. 13.

Finally, there is the **Infrared Multispectral Scanner (IR-MSS)** that will operate in 4 spectral bands: one is a panchromatic band(PAN), two of them are positioned in the short wave infrared (SWIR), and one is in the thermal infrared (TIR). The IR-MSS will produce images of a path 120 km wide, with spatial resolution of 80m (PAN and SWIR) and 160m (TIR). Its temporal resolution is 26 days. The spectral response functions (SRF) of this camera were not reported by the China Academy of Space Technology (CAST), which has made simulation of this data impracticable.

3. AVIRIS SENSOR

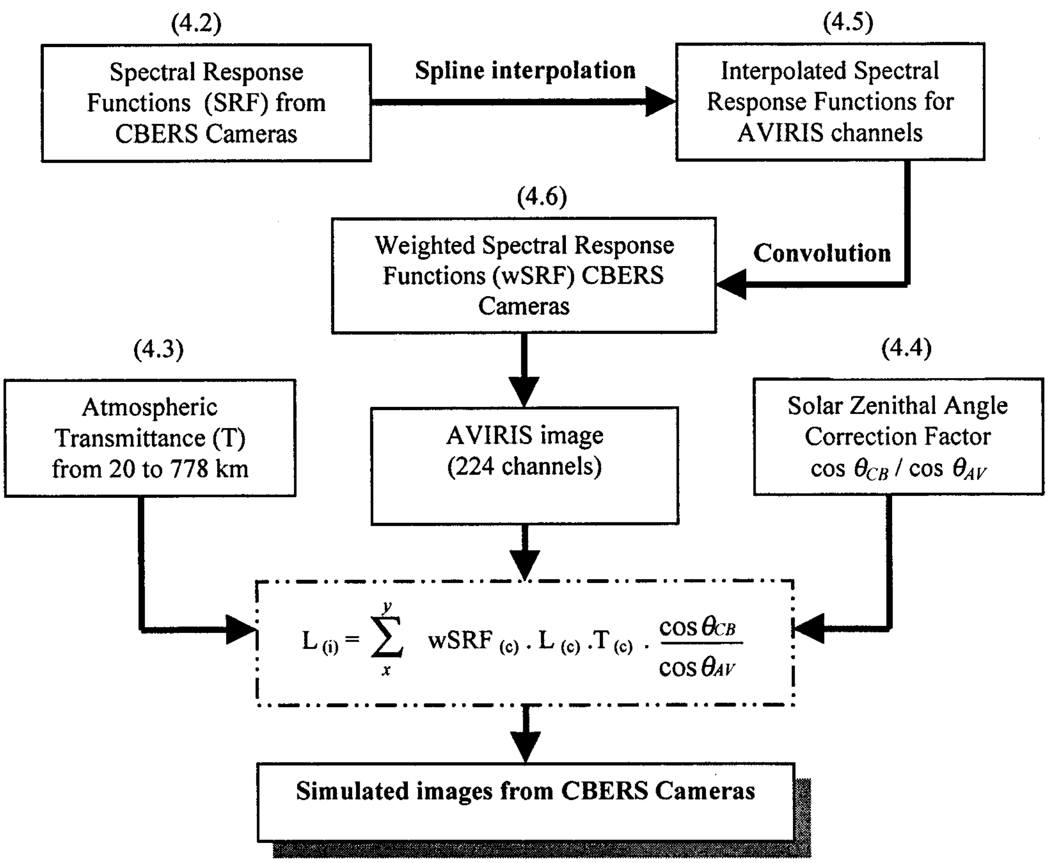
The *Airborne Visible/Infrared Imaging Spectrometer* (AVIRIS) developed by NASA/JPL, entered in operation in 1987 to be the first imaging system that acquires data on 224 narrow contiguous spectral bands across the solar reflected portion of the electromagnetic spectrum, from 0,4 _m to 2,5 _m (Vane et al., 1984). AVIRIS is operated from the NASA ER-2 airplane that flies in an altitude of 20 km.

Two movements define AVIRIS images: the first refers to the displacement of the airplane at 20 km of altitude, which defines the image length. The second refers to mechanical scanning, characterized by an imaging line with 614 pixels wide, which corresponds to a strip on the ground with 10,5 km , perpendicularly to the flight direction. The instantaneous field of view (IFOV) has 1 mrad, which gives a pixel of 20m.

4. SIMULATION METHOD OF THE IMAGES FROM CBERS

4.1 SIMULATION METHOD FLUXOGRAM

The **Figure 1** presents the simulation algorithm used in this study. The number between parentheses above each block indicates the section where are detailed each step of this



simulation.

Fig. 1 – Image simulation algorithm from CCD and WFI cameras

4.2 –SPECTRAL RESPONSE FUNCTIONS OF CCD AND WFI CAMERAS.

To simulate the images from CBERS, the AVIRIS spectral bands must pass through a convolution algorithm that simulates the bands of the satellite sensors. The spectral response functions of the sensor filters, obtained in laboratory, are required for this algorithm, because they determinate how much each wavelength contributes to the CBERS spectral bands. **Figure 2** shows the measured spectral response function of each CCD band. The spectral bands numbered B1 to B5 refers to blue, green, red, near-infrared and panchromatic bands respectively. **Figure 3** shows the spectral response functions measured on the WFI filters. The spectral bands B10 and B11 refers to the red and near-infrared, respectively. The symbols that appear on the curves show the wavelengths measured in the laboratory.

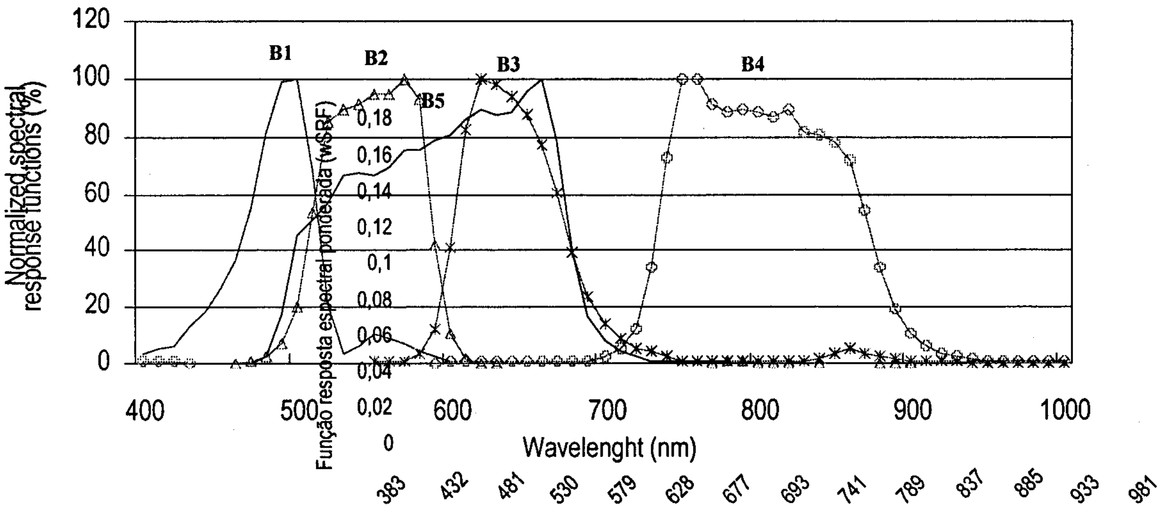


Fig. 2 – Normalized curves of the spectral responses of CCD camera
Font: adapted from CAST (1997), p. 19 – 21.

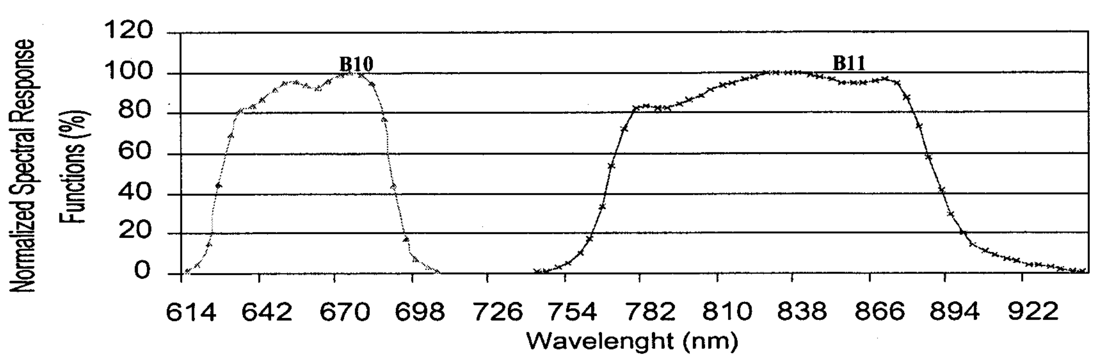


Fig. 3 – Normalized curves of the spectral responses of WFI camera
Font: adapted from Santana (1997)

4.3 – ATMOSPHERE TRANSMITTANCE

To achieve the simulation of the CBERS images, it is necessary to extrapolate the spectral radiance measured by AVIRIS at 20 km high to the CBERS orbit at an altitude of 778 km. The transmittance of this upper atmosphere thickness was calculated and multiplied by the AVIRIS spectral images to extrapolate the radiance measured by AVIRIS to the CBERS orbit. The MODTRAN 3.0 software was used to calculate the transmittance values at each wavelength. **Figure 4** presents the atmospheric transmittance result and shows that the values are close to unity, except for week absorption due the ozone, oxygen, and carbon dioxide, in restricted portions of the spectrum.

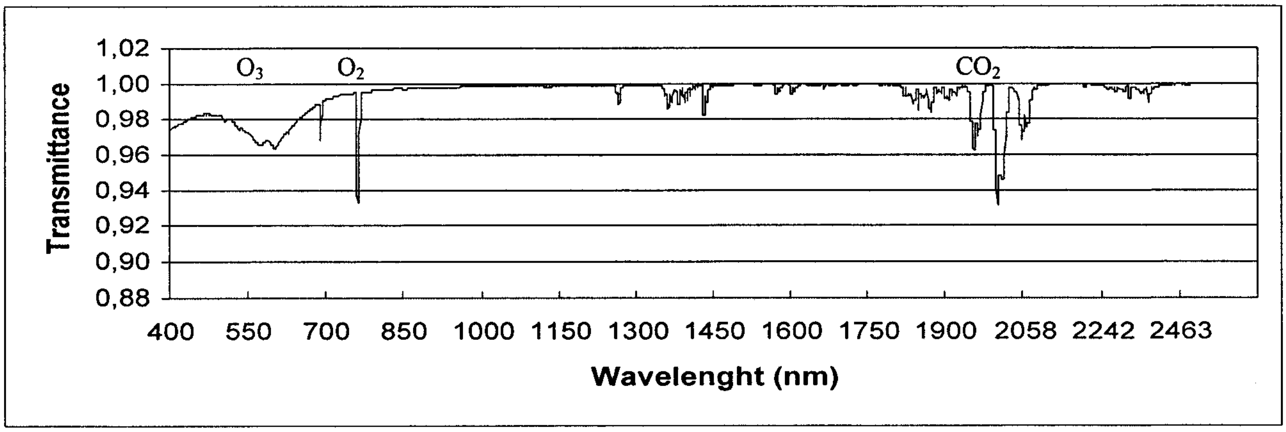


Fig. 4 - Atmosphere transmission from 20 to 778 km

4.4 – SOLAR ZENITHAL ANGLE CORRECTION FACTOR

The satellite CBERS is programmed to pass the equator at 10: 30 h, local time, but the AVIRIS images were collected at different times. While in Brazil, the ER-2 typically took off between 13:30 and 16:30 GMT for 4 to 8 hours flights. During the acquisition of the images, AVIRIS collected information about the time and geographic position, giving a quantitative basis to know the illumination conditions of the scene. With this information the solar zenithal angle was calculated for the AVIRIS data. The nominal CBERS satellite zenith was calculated as well. These data were used to calculate a nominal zenith angle correction factor. This factor is given by the expression, $\mathbf{\cos_{\_CB}/\cos\_{}_{AV}}$. This factor assumes a Lambertian scene and does not correct for bidirection reflectance distribution or shadows.

4.5 – INTERPOLATION OF CBERS SPECTRAL RESPONSE FUNCTIONS TO THE AVIRIS CORRESPONDING CHANNELS

The CCD and WFI spectral response functions measured in laboratory (Figures 2 and 3) were transformed by a spline interpolation algorithm. This algorithm interpolates the CCD and WFI spectral response function to match the central wavelength value of each AVIRIS narrow band. This allows the construction of an interpolated spectral response function (Figure 5). The bands numbered B1 to B5 refers to **CCD** blue, green, red, near-infrared and panchromatic channels, and the bands numbered B10 and B11 refers to **WFI** red and near-infrared channels.

4.6 – VECTORS FOR THE SPECTRAL CONVOLUTION

With the interpolated functions to the AVIRIS channels, a convolution algorithm is applied to create the weighted spectral response functions (wSRF). For this convolution, we used the interpolated CBERS response functions and the narrow AVIRIS bands. AVIRIS bands are 10 nm wide with Gaussian shapes. As a result of this algorith, values that represent the weight of each AVIRIS channel on the CBERS spectral response were generated. The weighted spectral response functions are shown in Figure 6. When multiplied by the AVIRIS spectra, these weighted spectral response functions produce the simulated spectral bands of the cameras of CBERS satellite.

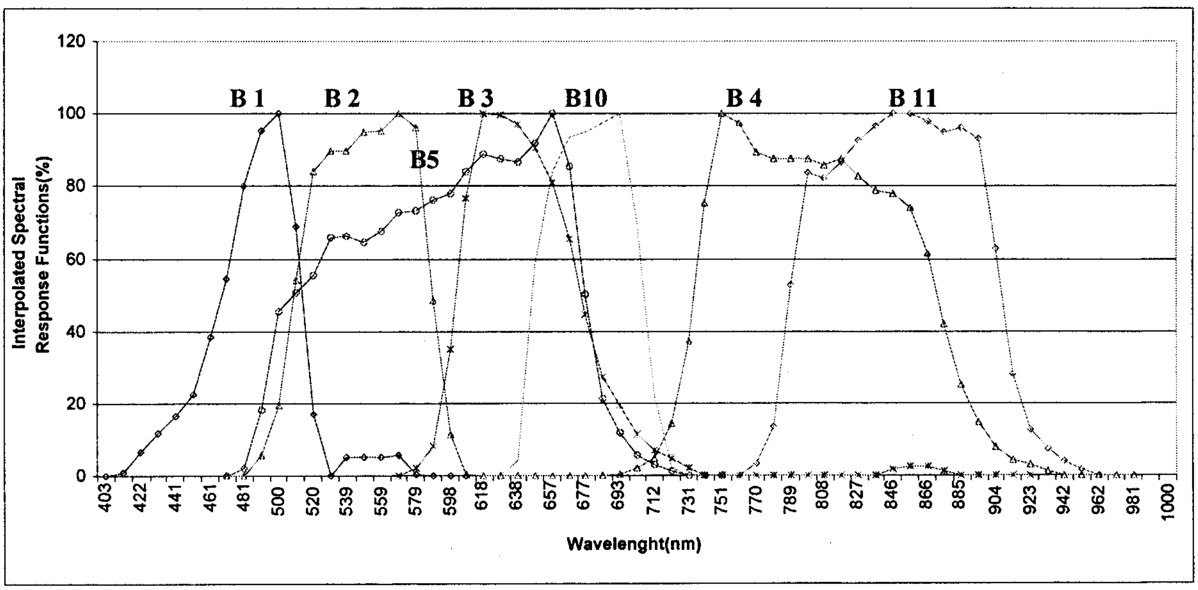


Fig. 5 – Spectral response functions of the interpolated bands CCD and WFI that corresponds to the AVIRIS spectral channels positions.

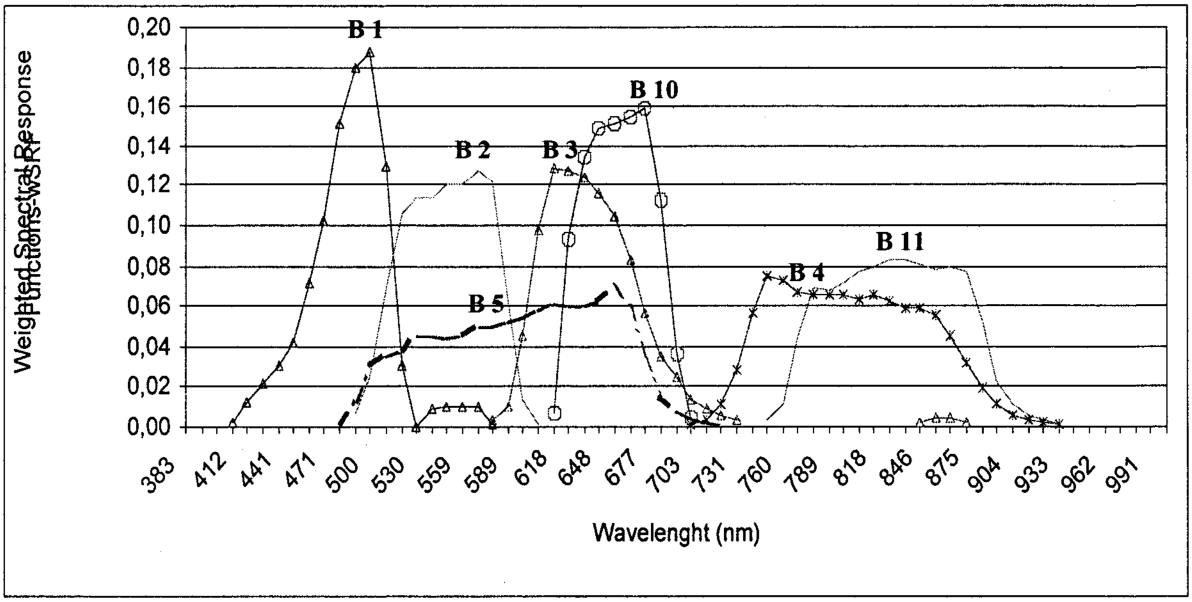


Fig. 6 – Weighted spectral response functions of the CCD and WFI cameras, that corresponds to the AVIRIS spectral channels positions

The convolution equation is given in Equation 1, where the wide band (*i*) of the CCD or WFI cameras is constructed from many AVIRIS narrow bands from *x* to *y*.

The simulated image radiance ($L_{(i)}$) is calculated by the summation of the product between weighted AVIRIS spectral response function($wSRF_{(c)}$) and the AVIRIS radiance ($L_{(c)}$) from each AVIRIS channel participating in the image formation:

$$L_{(i)} = \sum_{x}^{y} wSRF_{(c)} \, . \, L_{(c)}. \tag{1}$$

Note that this operation is done pixel by pixel. Moreover, in this simulation, the atmosphere transmittance ($T_{(c)}$) and the solar zenithal angle correction factor ($\cos_{CB}/\cos_{AV}$) are placed into the model according to **Figure 1.**

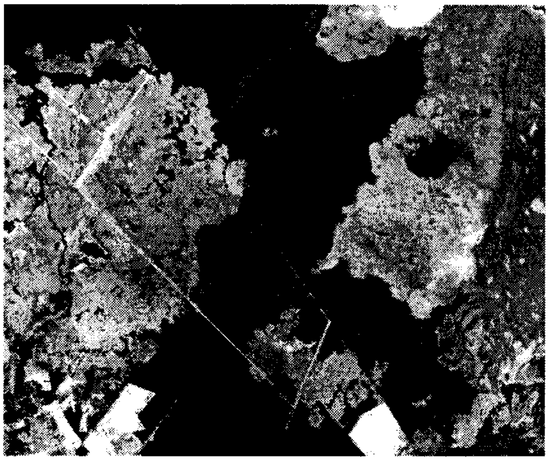
5. SIMULATED IMAGES

The simulated images of each test area are present in a standardized form, in order to facilitate visualization and interpretation. On the same page, the five bands of the CCD camera are presented individually with a colored composition associating the near-infrared band (4) to the red channel; the red band (3) to the green channel and the green band (2) to the blue channel. In the simulations of the WFI camera, the red (10), and near infrared (11) bands are shown individually with a ratio between bands 11 and 10. This ratio image gives us the chance to make colored compositions.

The simulations were calcualted for images of urban areas (part of the city of Cuiaba), forested (area near to Porto Nacional), flooded areas (Pantanal Mato-grossense), cultivated areas (north of Brasilia), burned areas (the same area of Cuiaba). These diverse areas permit evaluation of the potentialities of the CCD and WFI cameras. Only the images from Porto Nacional are presented, like as example, due the page limit of this paper.

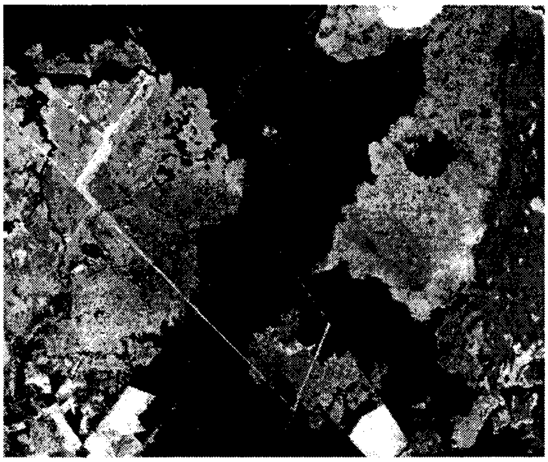
5.1 – PORTO NACIONAL

The colored composition of the CCD camera (figure 7) shows, in red, the areas that correspond to the dense vegetation, characterized by a high radiance response on the infrared channel and low on the visible spectrum channels. The areas in blue, on the right lateral of the scene, represents lower and more humid pasture areas, and the other greened areas indicate not-so-wet pasture areas, with different methods of cattle grazing. The blank area in the lower margin of the scene corresponds to a recent deforestation. The figure 8 shows the WFI simulation to the same scene.

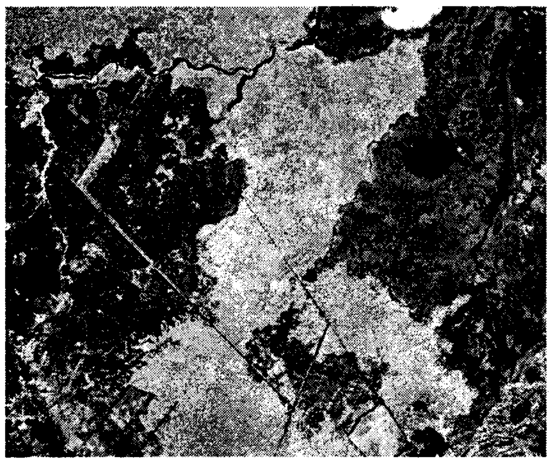


Band 1-CCD (450 a 520 nm)

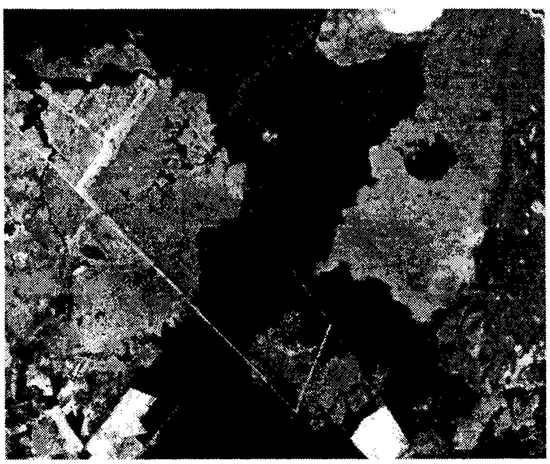
Band 2-CCD (520 a 590 nm)



Band 3-CCD (630 a 690 nm)



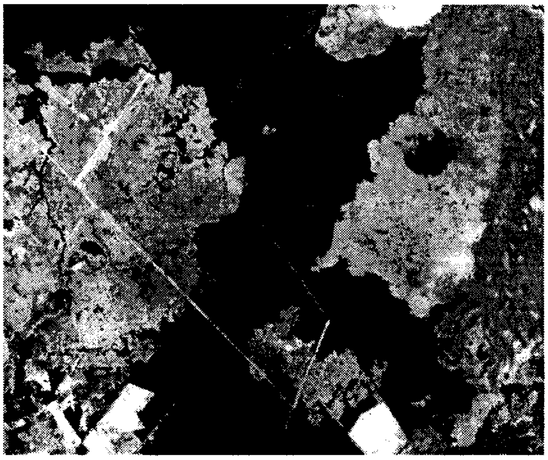
Band 4-CCD (770 a 890 nm)



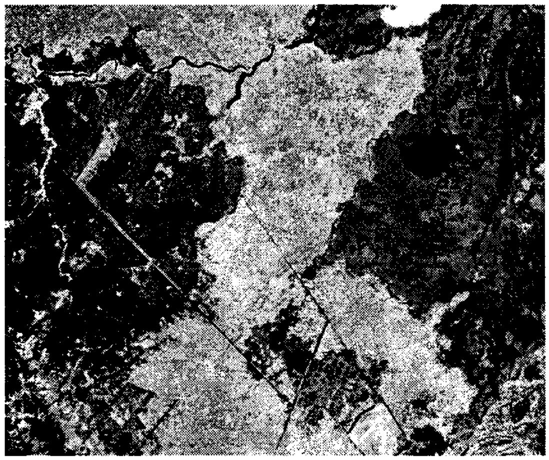
Band 5 -CCD (510 a 730 nm)

Composition IR/R/G - CCD

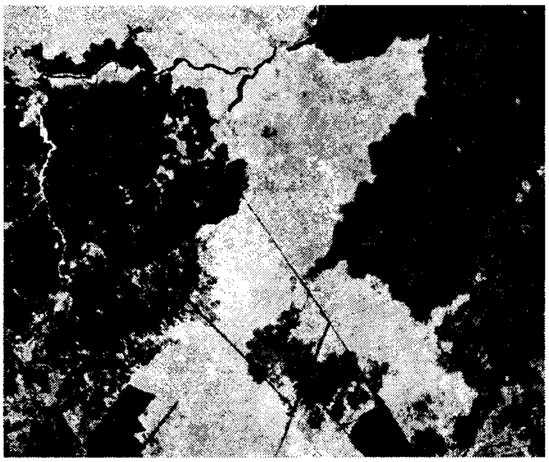
Fig.7 – Simulated image CCD camera. Porto Nacional area Latitude: $11^{0}12'$S Longitude: $049^{0}50'$W. :August 20th of 1995.



Band 10-WFI (630 a 690 nm)



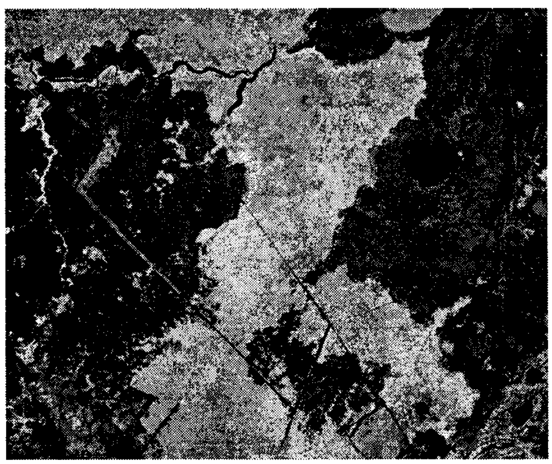
Band 11-WFI (770 a 890 nm)



Band Ratio IR:R

Composition: R / IR / Ratio IR:R-WFI

Composition: Ratio IR:R / R / IR-WFI



Composition: Ratio IR:R / IR / R -WFI

Fig.8- WFI camera simulated images. Porto Nacional Area - Latitude: 11^{0}12'S Longitude: 049^{0}50'W. August 20th of 1995.

6.CONCLUSION

Simulation of multispectral imaging systems by hyperspectral sensors permits the investigators to evaluate in advance to potentialities of the multispectral sensor. The proposed reached results and objectives of the multispectral sensor may be assessed. This simulation capability provides an opportunity to try variations in the original spectral intervals and to adjust the spectral bands to achieve best results for the multispectral sensor objectives.

Hyperspectral sensors such as AVIRIS open the opportunity to fully simulate multispectral imaging systems that are still on the drawing board. To use this approach it is essential to establish controlled field data from the test sites. These should be defined according to the desired applications of the multispectral sensor. The combination of hyperspectral images for simulation with field data in designated investigator sites will contribute on the improved definition of multispectral sensors bands.

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